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MECHANICAL BEHAVIOR AND CHARACTERIZATION OF STIR CASTED AZ31-$CaSiO_3$ METAL MATRIX COMPOSITES

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ABSTRACT

Metal Matrix Composites (MMCs) are widely used in many engineering applications nowadays and play a key role, especially AZ31 magnesium alloy got much importance due to its specific characteristics suitable for both Engineering and Biomedical fields. In this work, MMCs with the pure AZ31 Magnesium alloy as matrix and Calcium silicate ($CaSiO_3$) as reinforcement were developed with a bottom pouring type stir casting machine in argon gas inert atmosphere. The percentage of $CaSiO_3$ has been increased from 2% to 8% in steps of 2% by weight. The microstructural analysis, X-ray diffraction (XRD) analysis and hardness tests have been performed and found that the reinforcement has been observed as $CaSiO_3$, which is distributed throughout the volume of the samples, no new phase or impurities were identified in the composites and composite with 98% AZ31 with 2% $CaSiO_3$ reveals better hardness values compared with other prepared composites.

KEYWORDS: AZ31, Calcium Silicate, Hardness Test, Magnesium Composite & Stir Casting

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Original Article

1. INTRODUCTION

In manufacturing a component, the material properties play a very important function in defining the mechanical features of component like strength, hardness, toughness, etc. Composite is a material termed as a combination of two materials affixed by adding them in different forms. The purpose of the combination of materials was done to enhance the specific features of materials that are most desirable in various industries like Automobile, Aerospace, Marine, etc., to withstand high temperatures and fatigue loads. Huan *et al*. (2016) [1] prepared a Metal Matrix Composite (MMC) with base of magnesium and calcium silicate as fortification by the Spark Plasma Sintering method at different proportions from 10% to 40% and tested for mechanical properties and biocompatibility. It was observed that the composite with 20% reveals superior properties like compactness, compressive strength and corrosion resistance than the base metal and other composites made by them. Shirazi *et al*. (2014) [2] studied the impact of aluminum oxide on α calcium silicate ceramic produced by a sintering process and found that alumina reacted with α-calcium silicate and produced alumina-rich calcium aluminates after sintering and adding aluminum oxide powder at 1250^0C causes hardness improvement of the calcium silicate. Ünal, T. G., & Diler, E. A. (2018) [3] studied that alloy of $AlSi_9Cu_3$ with Al_2O_3 micro- and nano-sized particles as reinforcement at different weight portions fabricated by stir casting routes and observed that it reveals a great influence on hardness and flexural

strength. Dey, A. and Pandey, K. M. (2015) [4] reviewed the effect of various fortification materials in a magnesium as matrix and observed that magnesium exhibits superior properties when it reinforced with ceramic particles. Hassan, S. F. and Gupta, M. (2005) [5] studied that hardness increase in the MMCs formed by Blend-Press-Sinter methodology with magnesium as base and various percentages of aluminum oxide nanoparticulates fortification.

Bodunrin *et al*. (2015) [6] reviewed the properties of hybrid Al-MMCs by mixing of various fortifying materials. Senthil Kumar, B. R. *et al*. (2016) [7] studied the influence of silicate particles along with fly ash when mixed with the aluminum metal matrix. Decrease in wear resistance and progress in mechanical properties were observed. Zulfia, A. *et al*. (2017) [8] studied the impact of Al-Si-Mg reinforced with SiC particle fabricated by the stir casting route. The optimum percentage of SiC was obtained for better tensile strength and hardness values. Ye, H. Z., & Liu, X. Y. (2004) [9] reviewed the convention and modern methods to produce Mg MMCs. The microstructure analysis with grain refinement and distribution reinforcement is analyzed. Witte, F. *et al.* (2007) [10] made an MMC with AZ91D as base and hydroxyapatite as reinforcement, found that the mechanical properties of the AZ91D-HA composite depend on particle size and distribution. Magnesium and Tin-based composites are produced by stir casting route by Poddar Palash *et al*. [11]. SiC micro-sized particles are used as reinforcement. It is observed that reinforcement particles are distributed uniformly and the hardness values are increased. Kondaiah *et al*. (2018) [12] made MMC with aluminium base and various fly ash percentages as fortification through stir casting route and investigated that hardness and wear resistance of fly ash is increased with the increase of fly ash. Sahu, M. K. *et al*. (2018) [13] discussed the influence of stirring process parameters like speed, feed, etc., on the dispersion of particles in matrix and influence on mechanical properties of materials, and suggested the optimum process parameters for stir casting. Dattatraya, N. L. *et al.* (2016) [14] studied the effects of process parameters in stir casting of Al and Al_2O_3 composites. V. V. Kondaiah *et al*. [15] observed the enhancement in the hardness of AZ31 and Fly-ash MMC. Suresh, G. *et al*. [16,17] analyzed microstructures and wear and corrosion resistance of Co-Cr-W alloy. Suneel Donthamsetty and Penugonda Suresh Babu [18] found that wear resistance of A356-SiC nano composites improved than pure A356 alloy. Suresh, G. *et al* [19-21] analyzed and processed the Co-Cr-W Alloy for density, hardness, elastic modulus, electrochemical behavior and bio compatibility of for Bio-Medical Uses.

In this work, composite is made by AZ31 alloy and Calcium silicate ($CaSiO_3$) with stir casting route at different weight proportions of $CaSiO_3$ and mechanical characterization is done. The $CaSiO_3$ is chosen as reinforcement because it improves mechanical properties and Bio-compatibility nature when it mixed with Magnesium [1–2]. The Microstructure, XRD analysis and Hardness tests are carried out and results are presented.

2. EXPERIMENTAL DETAILS

2.1. Materials

In the preparation of AZ31-CaSiO3 MMCs, AZ31 Magnesium alloy is used as Matrix and the Calcium Silicate ($CaSiO_3$) in white cream powder form used as reinforcement. In these MMCs, the proportion $CaSiO_3$ (by weight) is varied from 2% to 8% in steps of 2%. By using Bottom Pouring Type Stir Casting Machine (Make: M/s. Swam Equip, Chennai, India) 05 numbers of AZ31-$CaSiO_3$ MMCs (including AZ31) were prepared, which are displayed in Figure 1(a) and 1(b). The weight percentage of $CaSiO_3$ used in each of them are tabulated in Table 1.

(a) Bottom Pour Stir Casting Machine **(b) Composites with different % of $CaSiO_3$**

Figure 1: Casting Machine and Composites.

Table 1: Percentage of Elements in Each Sample (MMC)

Sl. No.	Sample Number	Percentage of Elements by Weight
1	Sample 1 (S-1)	100% AZ31, 0% $CaSiO_3$
2	Sample 2 (S-2)	98% AZ31, 2% $CaSiO_3$
3	Sample 3 (S-3)	96% AZ31, 4% $CaSiO_3$
4	Sample 4 (S-4)	94% AZ31, 6% $CaSiO_3$
5	Sample 5 (S-5)	92% AZ31, 8% $CaSiO_3$

2.2 Mixing Parameters

In the matrix of MMC, the spreading of reinforcements is influenced by stirring process parameters. The optimum stirring parameters are taken from previous work done by Sahu *et al*. [13]. The general process parameters like the speed of stirrer, rpm of the stirrer, stirring time, etc., are considered.

The temperature of mixing and depth of immersion are studied by suggested optimum parameters for proper mixing of matrix and reinforcement. The optimum stirring parameters are considered in making the composite of AZ31 as Matrix and $CaSiO_3$ as reinforcement, and the parameters which were considered for uniform mixing of $CaSiO_3$ in a matrix of AZ31 magnesium alloy are displayed in Table 2. The mixing process was performed in the medium of Argon gas as inert atmosphere. Then, molten metal has been sent to the casting process. The gravity Die-Casting is chosen for this work.

Table 2: Optimum Parameters for Uniform Mixing of Reinforcement in Matrix

Sl. No.	Process Parameters	
1	Stirring temperature	850^0C
2	RPM of the stirrer	550
3	Time of stirring	10 min
4	Depth of immersion	$1/3^{rd}$ from bottom

The samples were cut from all five samples at the appropriate place and processed for microscopic examination. Initially, these were polished in different grades of emery papers. Later, they were polished on a disc polishing machine using diamond paste. Picric acid was used for etching the samples and those were cleaned in ethanol and dried. The

microscopic examination was carried out with Optical Microscope. The pure metals Mg, Al, Zn, ceramic $CaSiO_3$ and fabricated composites were characterized by X-ray diffraction (Make: Bruker D8 Advance, Copper target) using CuKα radiation (λ = 1.54Å) at a scanning rate of 1 step/s and step size of 0.1°/step. Samples were chosen from three different areas.

2.3. Hardness Test

The hardness tests were performed on both macro and micro levels by using Vickers hardness test apparatus on all the 05 individual samples, which were cut from the concerned five MMCs.

2.3.1. Macro Level Vickers Hardness Test

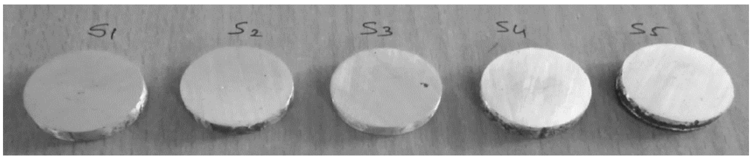


Figure 2: Samples of Specimens used for Microhardness Testing.

(a) Vickers Hardness Testing Machine (b) Micro Vickers Hardness Tester

Figure 3: Hardness Testing Apparatus.

For all cut samples, as displayed in Figure 2, the hardness test was done by using Vickers Hardness testing Machine (Make: FIE, Maharashtra, India. Model: VM-50) displayed in Figure 3(a) with the load of 5 kgf at different locations of the sample to find the average hardness values, and the results are mentioned in Table 3.

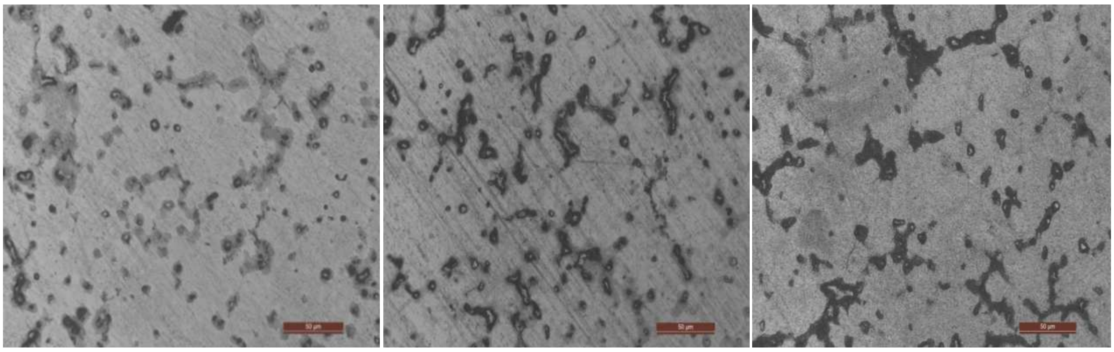
2.3.2. Micro Level Vickers Hardness Test

On different cut samples as displayed in Figure 4. The microhardness test was done by using Vickers Micro Hardness Tester (Make: Metco, Chennai. Model: Econometr VH1 MDX) as displayed in Figure 3(b) with 1 kgf load for 10 seconds' duration at different locations of the sample to find the average hardness values and the results are mentioned in Table 5.

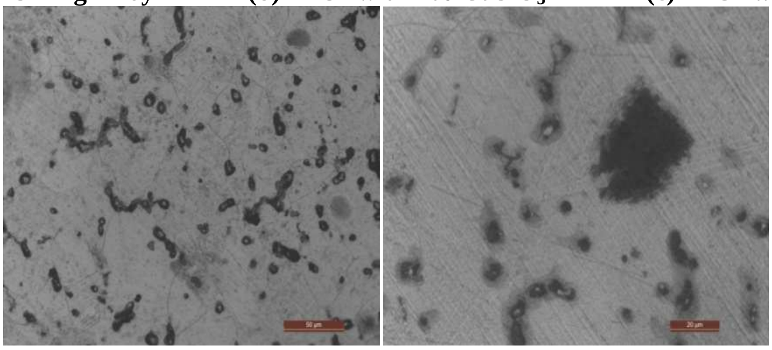
Figure 4: Samples of Specimens used for Microhardness Testing

3. RESULTS AND DISCUSSIONS

3.1 Microstructural Analysis



(a) AZ31 Mg Alloy **(b) AZ31 with 2% $CaSiO_3$** **(c) AZ31 with 4% $CaSiO_3$**



(d) AZ31 with 6% $CaSiO_3$ **(e) AZ31 with 8% $CaSiO_3$**

Figure 5: Microstructures of All Five Samples.

The microstructures of Pure AZ31 and composites made with different proportions of $CaSiO_3$ are displayed in Figure 5. The three important phases of AZ are observed in microstructural study. Those are the solid solutions of Mg and Al (α-Phase), Intermetallic phase formed between Mg and Al (Mg_{17} Al_{12}) and eutectic region of α-Mg & Mg_{17} Al_{12}.

3.2 XRD Analysis

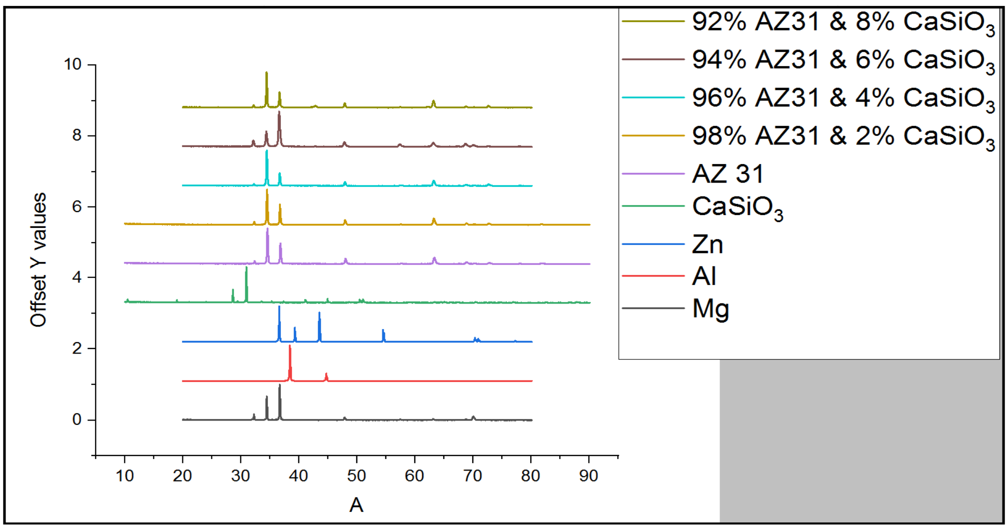


Figure 6: XRD Analysis of Pure Mg, Al, Zn and $CaSiO_3$ with Compositions.

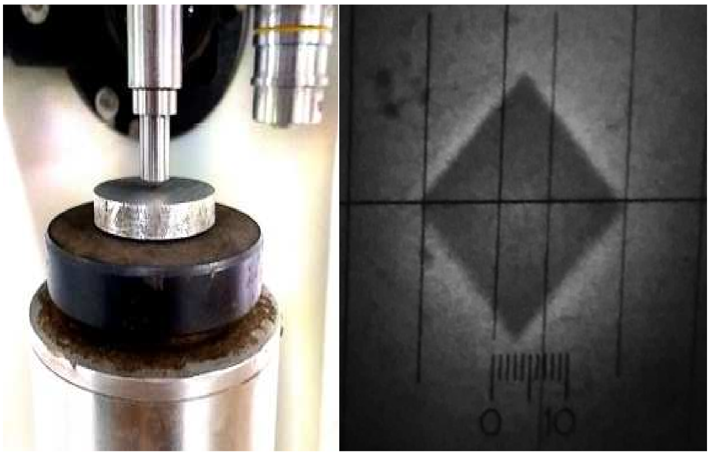
In the XRD analysis, Pure Mg, Pure Al, Pure Zn and Pure $CaSiO_3$ were confirmed by comparing standard XRD plots displayed in Figure 6. No new phases were found in composites that indicate that the produced composites have

AZ31 as matrix and $CaSiO_3$ as reinforcement. It is observed from XRD plots, the peaks corresponding to $CaSiO_3$ were not visible. This may be due to the lower amount of $CaSiO_3$ than the detecting range of XRD.

3.3 Vickers Hardness Test

3.3.1 Macro level

Vickers Hardness test (at macro-level) was done for all the 05 samples separately at different locations of each sample with 5 kgf load and concerned readings along with hardness values in HV were taken. Average hardness value of each sample is calculated and results are mentioned in Table 3. The sample and loaded indenter are displayed in Figure 7(a) at 5 kgf load on macro Vickers hardness tester and the corresponding indentation mark on sample is displayed in Figure 7(b).



(a) Sample and Indenter (b) Diamond Indentation

Figure 7: Diamond Indentation Formed on the Sample at 5 kgf Load.

Table 3: Hardness Test Readings at Various Positions and the Average Value

Vickers Hardness Test Values at 5 kgf Load												
Sample No.	**Trail No.->**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
S-1	Reading value in M/C	0.341	0.337	0.342	0.349	0.349	0.344	0.342	0.339	0.337	0.341	0.3421
	Hardness HV @ 5 kgf	79.7	81.6	79.3	76.1	76.1	78.4	79.3	80.7	81.6	79.7	**79.25**
S-2	Reading value in M/C	0.332	0.345	0.332	0.327	0.333	0.331	0.326	0.328	0.332	0.328	0.3314
	Hardness HV @ 5 kgf	84.1	77.9	84.1	86.7	83.6	84.6	87.2	86.2	84.1	86.2	**84.47**
S-3	Reading value in M/C	0.357	0.353	0.343	0.349	0.351	0.352	0.349	0.352	0.353	0.351	0.351
	Hardness HV @ 5 kgf	72.8	74.4	78.8	76.1	75.3	74.9	76.1	74.9	74.4	75.3	**75.3**
S-4	Reading value in M/C	0.371	0.331	0.346	0.328	0.327	0.329	0.331	0.333	0.329	0.342	0.3367
	Hardness HV @ 5 kgf	67.4	84.6	77.5	86.2	86.7	85.7	84.6	83.6	85.7	79.3	**82.13**
S-5	Reading value in M/C	0.331	0.337	0.339	0.335	0.335	0.332	0.334	0.338	0.334	0.339	0.3354
	Hardness HV @ 5 kgf	84.6	81.6	80.7	82.6	82.6	84.1	83.1	81.2	83.1	80.7	**82.43**

To make a clear identity of the average hardness value of Vickers hardness test conducted, the average hardness values are mentioned in Table 4 and the concerned graph has been plotted in Figure 8.

Table 4: Average Vickers Hardness Values of Specimens (at 5 kgf Load)

Sample Number	S-1	S-2	S-3	S-4	S-5
Average Value	79.25	84.47	75.3	82.13	82.43

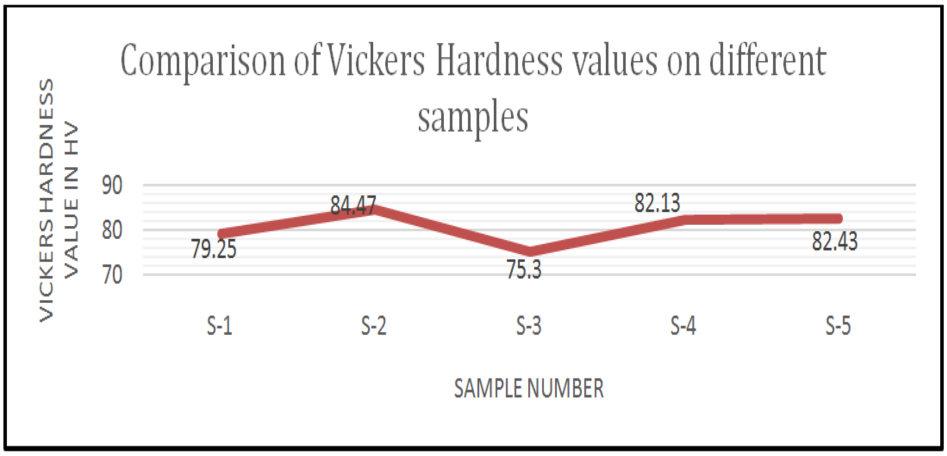
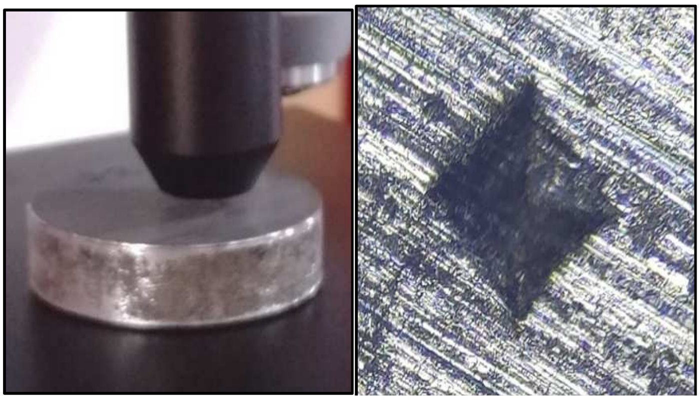


Figure 8: Average Vickers Hardness Test Values (at 5 kgf Load).

The above result displays that S-2 sample of 2% $CaSiO_3$ and 98% of AZ31 Magnesium alloy giving maximum hardness.

3.3.2. Micro Level

The hardness test was conducted on all samples using micro Vickers hardness tester at 1 kgf load applied for 10 seconds. The sample indent (with diamond pointer) of 136^0 was applied on the specimen to find the value of HV and the results are mentioned in Table 5. The sample and loaded indenter are displayed in Figure 9(a) at 1 kgf load on micro Vickers hardness tester and the corresponding indentation mark at 10x on sample is displayed in Figure 9(b). The graph has been plotted for samples of average hardness values, which is displayed in Figure 10.



(a) Sample and Indenter (b) Diamond Indentation

Figure 9: Diamond Indentation formed on the Sample at 1 kg Load (at 10X).

Table 5: Hardness Values in HV under Micro Hardness Tester (at 1 kgf Load)

Sample Number	D1 Value	D2 Value	Average HV Value
S-1	314.01	300.73	19.6
S-2	253.01	251.63	29.1
S-3	328.86	344.66	16.3
S-4	309.63	318.70	18.7
S-5	276.21	276.21	24.3

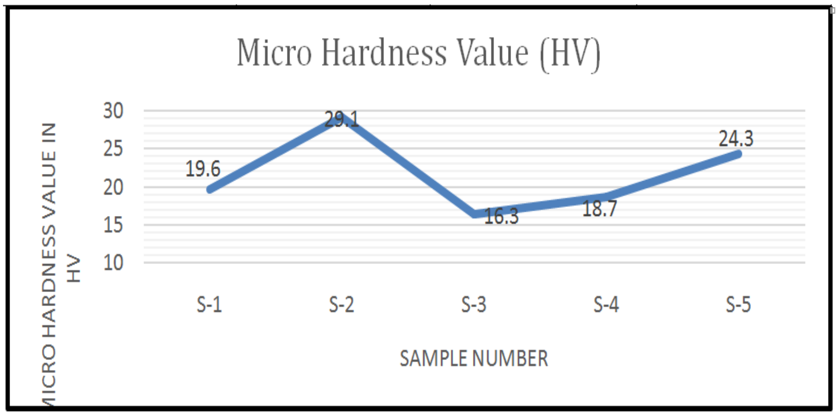


Figure 10: Microhardness Value (at 1 kgf Load).

By observing the results obtained by experimentation on hardness tester from Table 5 or from Figure 10, the S-2 sample reveals the maximum value as 29.1 HV like the macro level hardness test as indicated above. Hence, 2% of $CaSiO_3$ is considered as optimum to improve the hardness of composites.

The reasons for increased hardness can be understood by considering the effect of the addition of $CaSiO_3$. When the second phase particles are spread in a matrix, the dispersion strengthening mechanism plays a crucial role to enhance the mechanical properties. However, further increase of the percentage of $CaSiO_3$ inappropriate bonding strength between the matrix and reinforcement along with agglomeration of the reinforcement, decreased the hardness. Hence, 2% of $CaSiO_3$ is considered as optimum to increase the hardness of composites.

4. CONCLUSIONS

AZ31 and $CaSiO_3$ composites have been made by using the bottom pour stir casting machine by varying the composition of $CaSiO_3$ percentage by weight. After conducting different tests, the following conclusions are derived.

- Microstructure and XRD analysis have been performed on the samples. The XRD plots of pure metals have been compared with standard plots and confirmed.
- No new phase was observed in the composites.
- The Vickers hardness test has been carried out at both macro and micro levels for composites. Among all the prepared composites, S-2 sample which comprises of 98% AZ31 and 2% $CaSiO_3$ composite reveals maximum hardness value, i.e., 84.47 HV with 5 kg applied force (macro) and 29.1 HV with 1 kg applied force (micro), hence it can be considered as optimum for getting maximum hardness strength for AZ31 and $CaSiO_3$ composites

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- Narasaraopeta Engineering College (NEC)-Autonomous, Narasaraopet for Vickers Macro Hardness Testing

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